## Title

# Development Of System Safety Performance Measures In Support Of The Global Analysis And Information Network



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# Development of System Safety Performance Measures in Support of the Global Analysis and Information Network

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## Preface and Acknowledgments

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The discussion of the potential application of technologies and data sources developed under the Aircraft Movement Area Safety System and the NASA Aviation Performance Measuring System are based on reviews performed as part of this project by Prof. Vojin Tosic and Dr. H.-S. Jacob Tsao. The author also wishes to acknowledge the assistance received from Dr. Yuri Gawdiak and Dr. Irving Statler at NASA Ames Research Center, Capt. Robert Lynch of the Battelle Aviation Safety Program, and Jack Wojciech at the FAA Office of System Safety. In the course of the project, helpful information and suggestions were received from a large number of people in the FAA and the aviation industry, as indicated in the Appendix.

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## Executive Summary

In May 1996, the Federal Aviation Administration (FAA) announced a new and innovative approach to reach the goal of "zero accidents," known as the Global Analysis and Information Network (GAIN). This is envisaged as a privately owned and operated international information infrastructure for the collection, analysis, and dissemination of aviation safety information that would involve the use of a broad variety of worldwide aviation data sources, coupled with comprehensive analytical techniques, to facilitate the identification of existing and emerging aviation safety problems. In support of this effort, the objective of the research project described in this paper is to assist the FAA in developing aviation system safety performance measures that can utilize the automated operational data that is available in the aviation system, such as digital flight recorder data and air traffic control (ATC) system data, to monitor trends in the operation of the aviation system and anticipate problems before they lead to incidents and accidents.

For this to be done, it will be necessary to develop effective techniques to manage the vast amounts of data involved and appropriate analytical techniques to sort through these data and apply formal models to identify situations of interest. The goal of the current phase of the research is to review the available data sources and the techniques that have already been developed by the airlines and FAA, in order to provide the FAA Office of System Safety with a roadmap of what could be done to utilize these data sources to develop safety performance measures and what additional resources this would require.

During the course of the research, discussions were held with some 25 people representing a broad range of FAA offices and industry organizations, including the FAA Office of System Safety, Office of Aviation Research, Air Traffic Service, Flight Standards Service, Office of System Capacity and the William J. Hughes Technical Center. Site visits were made to gather information on the FAA Airport Movement Area Safety System, and the NASA Aviation Performance Measuring System and Surface Movement Advisor program. Information was

assembled on existing sources of operational data and data analysis tools, including those developed to support Flight Operations Quality Assurance programs.

Development of the type of system safety performance measures discussed in this concept paper offers the potential to provide three useful contributions to improving aviation safety. The first is to provide a means to monitor progress toward achieving the FAA goal of reducing the fatal aviation accident rate by 80% by 2007. Since aviation accidents, particularly for commercial airline operations, are relatively rare events, it will take many years of data before any change in the underlying accident rate can be established with any confidence, much less the effect of any particular set of measures to improve the level of safety. Therefore, what are needed are performance measures that are responsive to procedural and technology changes, and measure events that occur much more frequently but reflect situations that those operating the system agree they wish to avoid, as well as conditions that aviation safety experts agree could be indicators of potentially hazardous situations. The second contribution is to provide a means for managers and supervisors to assess the effectiveness of operational changes, to identify locations or procedures that appear to generate a high number of undesired situations, and to tailor the training of flight crews and controllers to help them improve their performance. The third contribution is to provide an early warning indicator of problems that may be emerging from the introduction of new technology, new procedures, and the growth in traffic levels.

For this to be achieved, it will be necessary to develop the appropriate performance measures in close collaboration with those involved in operating the system on a day-to-day basis, and to encourage a thoughtful debate on how to measure safety within the NAS and how to improve it.

The operational aspects of computing appropriate performance measures are likely to be at least as difficult as deciding what to measure. Fortunately, there already exists considerable experience working with aircraft flight recorder data, and specialized analysis tools have been developed and continue to be developed, by both commercial vendors and government agencies. There is also considerable experience within the FAA and other organizations in working with radar flight track data. Experience in applying these and similar techniques to the development of system safety performance measures will determine what is useful, and whether the effort involved is justified by the results. Therefore it is proposed that a limited number of proof of concept studies should be undertaken as soon as possible to gain experience in developing appropriate analysis tools and techniques, as well as to begin involving the operating community in the process.

One such study has already been proposed by researchers at NASA Ames Research Center to explore the application of concepts and techniques developed under the NASA Aviation Performance Measuring System to air traffic control system data. This has been jointly funded by the NASA Aviation Safety Program and the FAA, and is about to commence. The study would utilize the Performance Data Analysis and Reporting System, that is currently under development, to examine routine operational data in order to identify exceedances from normal operations.

While the development of a comprehensive approach to measuring system safety performance needs to integrate all available information, including that derived from monitoring aircraft flight operations, as well as the operation of the ATC system, there are immediate opportunities to identify and track safety performance measures using ATC system data. Developing and implementing these measures can not only provide near-term indicators of system performance, but in the longer term can provide a consistent data stream that can be integrated into a more comprehensive framework as the other elements of this framework are implemented.

It is recommended that at least two other studies be initiated addressing this aspect of the system, one focusing on terminal airspace operations and the other on airport surface operations. The first study would utilize existing tools, such as those being developed under the NASA Aviation Safety Program, to analyze radar track and system message data for a Terminal Radar Approach Control facility to identify situations that represent a departure from normal operations, including atypical controller intervention to maintain separation, unstabilized approaches, and Traffic Alert and Collision Avoidance (TCAS) alerts. The second study would explore how to effectively utilize the available sources of data on aircraft movement on the airport surface to implement safety performance measures, and would develop algorithms for extracting and analyzing data on the aircraft paths on the taxiway and runway system. The scope and level of effort of these studies could be tailored to the available resources, but it is envisaged that each of these studies would last between six months and a year, and would require between one and two person-years of effort.

**Introduction**

On May 9, 1996, the Federal Aviation Administration (FAA) announced a new and innovative approach to reach the Administrator's goal of "zero accidents," known as the Global Analysis and Information Network (GAIN). GAIN is envisaged as a privately owned and operated international information infrastructure for the collection, analysis, and dissemination of aviation safety information. It would involve the use of a broad variety of worldwide aviation data sources, coupled with comprehensive analytical techniques, to facilitate the identification of existing and emerging aviation safety problems. In support of this effort, the objective of this research project is to assist the FAA in developing measures of aviation system safety performance that can utilize real-time data streams to monitor trends in the operation of the aviation system and anticipate problems before they lead to incidents and accidents.

In addition to the databases that are derived from investigation or reporting of incidents and accidents, a vast amount of automated operational data is available, such as digital flight recorder data and ATC system data. In general, most of these real-time data streams provide a unique opportunity to support the development of system safety performance measures that could be used to monitor trends in the operation of the aviation system and anticipate problems before they lead to incidents and accidents.

For this to be done, it will be necessary to develop effective techniques to manage the vast amounts of data involved and appropriate analytical techniques to sort through these data and apply formal models to identify situations of interest. The goal of the current phase of the research is to review the available data sources and the techniques that have already been developed by the airlines and FAA, in order to provide the Office of System Safety with a roadmap of what could be done to utilize these data sources to develop system safety performance measures and what additional resources this would require.

Scope of the Study

This phase of the project involved three tasks:

- Meet with appropriate staff at FAA and NASA Ames offices involved with aviation system monitoring and modeling, and safety data staff specialists at the Air Transport Association and selected airlines to review their experience with collecting and analyzing automated operational data.

- Review current procedures to archive FAA radar data, and available tools to extract and synthesize that data. This task involved coordination with ongoing efforts at NASA Ames to improve terminal area productivity and airport surface movement operations, as well as FAA and NASA efforts to develop a safety risk assessment model known as the "Reduced Aircraft Separation Risk Assessment Model" (RASRAM).

- Prepare a concept paper that discusses how the FAA might use the data sources identified in the first two tasks to develop system safety performance measures, estimates the scale of the effort required to assemble and analyze the data on a routine basis, and identifies the data management and analysis tools required.

During the course of the research, discussions were held with some 25 people representing a broad range of FAA offices and industry organizations, including the FAA Office of System Safety, Office of Aviation Research, Air Traffic Service, Flight Standards Service, Office of System Capacity and the William J. Hughes Technical Center. Site visits were made to gather information on the FAA Airport Movement Area Safety System, and the NASA Aviation Performance Measuring System and Surface Movement Advisor program. Information was assembled on existing sources of operational data and data analysis tools, including those developed to support Flight Operations Quality Assurance programs.

## Defining Safety

The development of system safety performance measures should be influenced by the way safety is defined in the National Airspace System (NAS). Obviously, at one level safety is an absence of accidents. However, this is not very helpful for defining performance measures that can be used to monitor the general level of safety in the system, since an absence of accidents provides no information about the likelihood of one occurring in the future. Aviation accidents are fortunately very rare, particularly for commercial aviation, and each one has its own unique circumstances. While a prolonged period with no accidents is certainly better than having a series of them, it provides no warning of a deteriorating situation or of a potential risk that could be reduced until the accident in question occurs. Thus what is needed are measures of the precursor events or situations that could lead to accidents. One such class of events are incidents that did not result in injury or damage, or even a violation of normal operating practice, but were of sufficient concern to those involved to be felt worth reporting.

The operation of aircraft in the NAS can be divided into three broad areas of concern:

1. The operation of the aircraft systems;
2. The operation of the aircraft itself, including maintaining safe separation from terrain and hazardous weather;
3. The maintenance of safe separation between aircraft.

The first area is primarily a matter of sound design and good maintenance, together with appropriate redundancy and training of flight crew to handle failures when they arise. Improvements in all aspects over the years has led to a dramatic reduction in the number of accidents that are attributable to failure of the aircraft structure or systems. Even so, accidents due to these causes continue to occur, as exemplified by the recent loss of TWA 800.

The second area is the primary responsibility of the flight crew, and is largely influenced by human factors concerns, although design of cockpit displays and automation is also an aspect of concern. This area is the focus of such programs as Crew Resource Management and Flight Operations Quality Assurance, and includes such safety concerns as controlled flight into terrain and loss of control accidents.

The third area is the primary concern of air traffic control, although under visual flight rules this is the responsibility of the flight crew. The advent of Traffic Alert and Collision Avoidance Systems (TCAS) has changed the relationship between the controllers and the flight crew, placing some separation assurance functions in the cockpit, even under instrument flight rules. Concepts being proposed as part of a broad initiative referred to as Free Flight may blur the distinction between the role of the controller and that of the flight crew even further.

Some incidents may span across more than one area, as when a mechanical problem distracts the flight crew and leads to a more serious or compounding error in operating the aircraft. Runway incursion incidents are generally due to flight crew error, although this may be precipitated by inadequate air traffic control instructions or a lack of clear signs or markings. While a comprehensive set of safety performance measures would address all three areas, since the first two areas are already the subject of well-established programs, this paper will focus on defining performance measures for the third area.

In this context, safety performance may be measured by the frequency of occurrence of events that are known to be likely precursors to incidents or accidents. For example, an aircraft making a wrong turn on the taxiways may suggest a loss of situational awareness or a misunderstood clearance, that could lead to a runway incursion.

Separation Standards

One complicating factor in any discussion of how to measure safety is the role of separation standards in air traffic control practice. The purpose of these standards is of course to maintain safety, and thus any violation of them is viewed as a serious matter. Indeed, it is considered by the FAA as an Operational Error, investigated and reported. Therefore at first glance, the frequency of such operational errors might be viewed as one potential safety performance measure, perhaps adjusted for the volume of the traffic being handled. However, another objective of the air traffic control system is to minimize the delay incurred by aircraft using the system. This requires separations between some aircraft to be reduced as much as possible, without violating the minimum separation standards. It is to be expected that a controller who is trying to get as much traffic as possible along a particular route may occasionally allow a pair of aircraft to get slightly closer than the minimum separation standard. Since these separations are anywhere from two and half to five miles, depending on the situation, if the two aircraft are going in the same direction at roughly the same speed, a slight loss of separation for a short time is clearly not a particularly dangerous circumstance. On the other hand, a loss of separation between two aircraft on converging flight paths, when the controller was not aware of the incipient loss of separation, could be a very serious situation indeed.

Thus, the mere fact of a loss of separation is not as important from a safety standpoint as the context of the situation under which the loss of separation occurred. Likewise, a situation in which separation was not in fact lost, but the controller had misjudged the aircraft flight paths and had not realized that they would pass as close as they did, could be far more serious from a safety standpoint that a situation in which separation was briefly lost, but the controller was well aware that this might happen and knew that it would be quickly restored.

Safety Performance Measures

At the highest level, the safety of the aviation system is measured by the number of accidents, or perhaps of more concern to the traveler, the probability of being involved in one. Thus such measures of safety performance might include the number of fatal accidents per 100,000 aircraft hours of operation or the probability of any passenger taking a flight being killed in an accident (Barnett and Wang, 1998). This outcome-oriented approach corresponds to the safety performance measures adopted in the FAA Strategic Plan (FAA, 1998):

- fatal aircraft accident rate
- overall aircraft accident rate
- fatalities and losses by type of aircraft
- occupant risk.

However, there are two reasons why other measures that focus on the causes of accidents rather than the outcome may be valuable. The first is that accidents, particularly for commercial airline operations, are relatively rare events. It will take many years of data before any change in the underlying accident rate can be established with any confidence, much less the effect of any particular set of measures to improve the level of safety. The second reason is that the introduction of new technologies or procedures, or simply the growth of traffic, may create hazardous situations that have never resulted in an accident before. Ideally, safety performance measures would provide warning of the potential risk before the first accident occurs. Therefore to contribute to reducing accidents, what is needed are measures of system performance that are responsive to procedural and technology changes, and measure events that occur much more frequently but reflect situations that those operating the system agree they wish to avoid, as well as conditions that aviation safety experts agree could be indicators of potentially hazardous situations. Thus one such measure might be the number of TCAS alerts within the airspace of a given air traffic control facility per thousand aircraft movements. Although each of these alerts may have been safely resolved, an increasing trend in the measure, or a level significantly higher than other comparable facilities, might indicate a potential problem with airspace procedures or operating practices deserving of further study.

Other safety performance measures may go beyond indicators associated with abnormal events (such as alerts) to seek situations which, while clearly within normal operating practice, indicate the *potential* for a hazardous situation to occur. For example, such an indicator might track the number of aircraft that were cleared to cross an active runway while a departing aircraft was being held on the same runway, or alternatively the number of aircraft that had to be held before crossing an active runway to allow a departure or arrival to pass.

Obviously there is a very large number of such potential performance measures. The challenge is to select a subset that provide valuable information and address the most serious safety problems. This suggests that the selection of such measures should proceed from an assessment of safety concerns rather than from a consideration of what data are available to implement the measures. One source of information on potential safety concerns is the NASA Aviation Safety Reporting System (ASRS). Since these are voluntary reports filed by aircrew (and to a lesser extent controllers) about incidents that have occurred and are judged serious enough to be worth reporting, presumably they reflect concerns about situations that may be occurring elsewhere in the system but not being reported. While the ASRS is subject to the limitations of a voluntary reporting system, it can serve to help identify potential situations that a safety performance measuring system could be programmed to monitor.

Operational Data Sources

The routine operation of the National Airspace System (NAS), and the aircraft using it, generates a large amount of operational data that can potentially be used to monitor the safety performance of the system. Until recently, most of these data have been neither preserved nor analyzed to study the performance of the system.

The FAA routinely records radar data, voice communications, and messages sent between the various computers that support the NAS. In essence, these data allow one to "play back" many of the events of a given day. Usually this is only done when an accident or incident occurs, and in fact the data tapes are typically recycled on a regular basis and the data are only preserved if needed for an investigation.

Some of the automation systems that have recently been developed or are currently under development offer significant promise to increase the amount of operational data available, as well as facilitate its use. One such example is the Aircraft Movement Area Safety System, which integrates information from Airport Surface Display Equipment radars and the terminal area surveillance radars to identify and alert controllers to runway incursions. While the frequency of such alerts may itself be a safety performance measure, the system records much more information about the operation of aircraft on the airport surface that can be used to identify situations that, while not triggering an alert, may still be indicative of an incipient safety problem. Another system is the Aircraft Situation Display (ASD), that integrates information from the Air Route Traffic Control Center host computers to provide a display of traffic at a national scale to support the traffic flow management process. While the aircraft position information is no different from that available at each Center for aircraft under positive control, the ASD program has already performed the data access and integration tasks.

Airlines, and to a lesser extent other aircraft operators, are increasingly preserving data on the operation of individual aircraft obtained from on-board data recorders, and analyzing these data to identify exceedances from normal operations. These efforts form the basis of several major programs to improve flight operations performance and are discussed in more detail later in this paper.

## Analytical Challenges

In order to implement the routine computation and reporting of safety performance measures derived from operation data, it is necessary to be able to scan the vast amount of operational data that are continuously generated by the system and identify and extract "interesting" events. Once the "fingerprints" of such events have been defined, it is then a matter of developing software to scan the various data files seeking these patterns. Where these patterns are clearly defined, such as a record of an alert going off, this task is fairly straightforward. However, where the event of interest is less clearly defined, such as an unusually high level of controller workload, it may not be so obvious how to identify this in the data stream. It may also be necessary to combine information from several data sources. Since operational data sources have generally not been designed to permit analysis of this sort, it will also be necessary to develop or adapt data acquisition tools to access and convert the data into a more usable format.

## Application of Safety Performance Measures

Apart from the direct use of safety performance measures to identify trends and problems in the operation of the national airspace system, they hold the potential to play another important role. There already exist a number of accident and incident databases, including voluntary safety reporting programs. However, the analysis of the data in these reports is limited by a lack of information on the context within which the event occurred. Such questions as how congested were the radio frequencies immediately prior to the event, how heavy was the workload of the controller at the time, or do certain types of incident occur more often during particular traffic patterns are difficult to analyze unless the relevant information was obtained during the investigation of the event or reported by those involved. The availability of system safety performance measures that include information of this nature, and that track the changes in the measures over time at each facility on a routine basis, would allow safety analysts to draw on this information for the specific time and location in question when analyzing incident and event reports.

## Related Programs

Since the development of system safety performance measures addresses fundamental concerns about the safety of the national airspace system, it is to be expected that this activity will overlap with related work under way in other programs. These programs address both the measurement of operational performance and the acquisition of data that could be used to support the development of safety performance measures. Although there are a large number of such programs that could impact this activity in one way or another, the current research examined four that appeared to have particular relevance.

### Flight Operations Quality Assurance

Although airlines have been using the output from flight data recorders to examine operational performance for many years, this activity has gained considerable momentum in recent years with the development of digital flight data recorders, which not only store a much greater amount of information, but simplify the data acquisition and analysis process. The use of flight data recorder (FDR) data to enhance crew training, flight deck and air traffic control procedures, maintenance activities, and address aircraft and airport design issues has come to be termed Flight Operations Quality Assurance (FOQA). In general, these programs do not obtain their information from the mandatory flight data recorders that commercial aircraft are required to have for accident investigation, but use a parallel recording system termed a Quick Access Recorder (QAR) that can record many more parameters than are required for the mandatory FDR and provides easier access for data retrieval.

In 1991, the FAA contracted with the Flight Safety Foundation (FSF) to examine the technologies, control processes, and benefits and costs of current FOQA programs, and to make recommendations for the implementation of FOQA programs in the U.S. airline industry. The resulting report (FSF, 1992) led to an on-going cooperative demonstration program between the

FAA and several airlines, in which the FAA provided the carriers with optical quick access recorders (OQARs), together with hardware and software to scan the disks (Wiley, 1997).

Under typical FOQA programs, the FDR data is analyzed to identify normal operating conditions and to set thresholds that can be used to identify exceedances from these conditions. These events are then examined in more detail to determine possible causes and potential corrective measures.

## Aviation Performance Measuring System

In 1993, the FAA and NASA commenced a collaborative program to develop a set of analytical tools and methodologies to allow the very large quantities of flight-recorder data to be processed in an automated way (NASA, 1995). This set of tools was termed the Aviation Performance Measuring System (APMS).

This program has built partnerships with several U.S. airlines, as well as the United Kingdom Civil Aviation Authority, the Netherlands civil aviation authority, and commercial vendors of flight data analysis software. User-needs studies have been undertaken, and software developed to analyze flight data and identify the occurrence of user-specified conditions, expressed using conditional rules (IF-AND-OR logic), as well as display a graphical representation of the data. Other analytical tools under development include products supporting statistical analysis, data reduction and exploration, and causal modeling (NASA, 1998).

## Airport Movement Area Safety System

This FAA program is designed to provide automated monitoring of runway operations, to detect runway incursions and alert the tower controllers. It combines data streams generated by the terminal airspace automation system (Automated Radar Terminal System (ARTS)) and the airport surface movement surveillance radar (Automated Surface Detection Equipment (ASDE)). Since even the latest ASDE version (ASDE-3) does not have the capability to establish the identity of specific targets, this information for arriving aircraft is obtained from the ARTS data feed and associated with the ASDE radar return when the aircraft is detected by that system. The Airport Movement Area Safety System (AMASS) monitors the movement of aircraft and vehicles in the vicinity of the runway, and generates an alert if a target begins to enter the runway safety area in front of an aircraft on takeoff or close enough on final approach to be considered a hazard.

The system is currently being tested at San Francisco International Airport. Data generated by the test have been recorded and are being analyzed at the Volpe National Transportation Systems Center. The potential value of the AMASS project to the development of system safety performance measures lies in the existence of the detailed recording of the surface movement data. While ASDE data are not typically currently archived, the corresponding data for the AMASS test site have been. Furthermore these data have been enhanced by the addition of aircraft identification tags. However, use of the data generated by the AMASS test at San Francisco is currently restricted by limitations on the use of the data that have been agreed between the FAA and the National Air Traffic Control Association.

Surface Movement Advisor

The Surface Movement Advisor (SMA) project is a joint FAA/NASA program to develop decision aids to allow airport facilities to operate more efficiently, by improving the coordination and planning of airport surface traffic operations. A proof-of-concept prototype demonstration has been undertaken at Atlanta Hartsfield International Airport, in which a range of real-time data, including airport surveillance radar data, weather data, aircraft flight plans, and airline flight information display system (FIDS) data, has been combined to provide information displays to FAA tower controllers and airline ramp controllers that show the sequence of aircraft arriving on each runway and their projected or actual touch-down time, as well as the projected or actual push-back times for each departure. This allows the FAA and airline controllers to better manage the flow of traffic.

Although the project has generated a large volume of historical data on traffic flows, it does not include airport surface movement radar data. Data collected during the project are being stored in an Oracle database to support subsequent analysis. The principal value of the project to the development of safety performance measures lies in the experience of working with real-time data feeds and developing the underlying database, as well as establishing closer coordination and data communications between the ATC tower and the airline ramp operations. Further investigation is required to identify how the information in the underlying database might be used, if at all, to support the development of a proof-of-concept study of system safety performance measures.

Performance Data Analysis and Reporting System

In order to support its Operational Performance Management efforts, FAA Air Traffic Services has undertaken the development of a Performance Data Analysis and Reporting System (PDARS). This system will collect, extract, and process flight operational data for use in performance analysis and computing operational performance measures on a regular basis, including measures related to system safety. This program is being pursued jointly with the NASA Aviation Safety Program, and work is currently under way to demonstrate the PDARS capability in a laboratory environment and integrate technology developed under the APMS program.[1]

The PDARS concept is based on collecting detailed air traffic management system data at individual air traffic facilities, processing the data locally, computing local performance reports, and extracting and communicating selected performance-related data for multi-facility and system-wide performance monitoring and reporting. Implementation of the PDARS concept is based on utilizing existing, proven, off-the-shelf software for extracting, processing, and analyzing air traffic data, networked in such a fashion to provide for transmission of operational data and performance measurement statistics among FAA facilities. When operational, PDARS will provide the capability to:

1) Collect, extract, and process radar data (and data from other sources) for use in performance analysis, including routine calculation of performance measures,

[1] Information on PDARS provided by Dr. Irving Statler, NASA Ames Research Center, and Dr. John Bobick, ATAC Corporation.

operational performance problem identification and analysis, and design and evaluation of choices to improve operations.

2) Compute quantitative operational performance measures on a regular basis (daily, monthly, annually, etc.) relating to system safety, delay, flexibility, predictability, user access, and any additional outcomes subsequently identified by the users and FAA as desirable.

3) Produce and disseminate performance measurement statistics on local air traffic control facility, regional, and headquarters levels.

4) Archive performance statistics and basic flight data for use in research, development, and planning studies and analyses.

5) Provide data and interfaces to tools for performance analysis and system modeling and simulation.

**Data Sources**

There are three broad categories of routine operational data that could be used to generate safety performance measures:

- aircraft operating data
- radar track and ATC automation system data
- radio communication recordings.

The use of flight data recorder information to analyze aircraft operational performance forms the basis of FOQA programs discussed above. While it would be technically possible to use the data derived from these programs to support the development of system safety performance measures, there are significant challenges to doing this in the foreseeable future. Perhaps the most serious are the airline concerns over sharing data derived from FOQA programs with the FAA, unless they are protected from subsequent use of the data for enforcement actions, or the broader use of operational performance data in a way that could have competitive or legal implications. There is also the practical constraint that not all airlines have implemented programs of this type, and even among those that have, the information that is obtained is far from standardized.

There are already significant efforts under way by both NASA and the FAA to support the development of FOQA programs and promote the sharing of information derived from these programs. While these programs contribute to improving safety, and can offer valuable insights into aspects of the system operation that FAA safety performance measures can track, the nature of the information currently derived from these programs does not easily lend itself to calculating such measures on a routine basis. What are needed are tools and procedures to convert the data derived from FOQA programs into information that can be used to support system-wide safety performance measures. Furthermore, many smaller airlines, including the regional airlines, have been deterred from implementing FOQA programs by the costs involved, and very limited consideration has been given to how FOQA-like programs might be implemented in the general aviation sector.

In contrast, ATC automation data offer a promising data source to support near-term development of system safety performance measures. These data are already controlled by the FAA and are fairly standardized across facilities. The two most significant elements of the data are the radar track data for each aircraft and the computer messages that are passed between the various components of the NAS. The radar data provides the position and altitude of each aircraft being tracked by the ATC system, apart from aircraft that have not set a unique transponder code or do not have an altitude-encoding transponder. The latter aircraft are typically low performance general aviation aircraft operating under visual flight rules (VFR), and are generally not operating in controlled airspace. Most VFR aircraft can be tracked from their transponder return, although very little is known about them other than their position and, in most cases, altitude.

Since uncontrolled VFR aircraft account for the greatest proportion of fatal accidents, the use of radar track data for these operations may represent an important opportunity to develop system safety performance measures for the general aviation sector.

While the voice message traffic on each ATC radio frequency is recorded, there is currently no easy way to analyze this information, apart from having someone listen to it and write down the information. This would be so labor intensive as to be quite impractical for routine use in developing system safety performance measures. The development of analytical techniques to automatically extract usable information from this source could form an important future research opportunity. The increased use of datalink communication between ATC and aircraft in the future will provide another source of information that will be much easier to analyze. However, voice radio communications are likely to remain a significant feature of the ATC system for some time to come.

The effective use and interpretation of any of these data sources requires the integration of the information obtained from all relevant data sources, including the data streams themselves, weather and system status information, accident and incident reports, crew reports, airline safety reports, operating procedures, and facility logs. However, the development of the data management systems to permit this integration will require a significant commitment of resources. Further research appears to be warranted both to document existing resources as well as to explore how these resources can be effectively integrated.

En-route and Terminal Data

Of the operational data routinely generated by the ATC system, en-route and terminal radar track and computer system message data are the most readily available to support the development of system safety performance measures. These data are recorded on disk packs or tapes at each facility, and kept for 14 days before the disk packs or tapes are reused.

The host computer software at the Air Route Traffic Control Centers records defined categories of transactions to System Analysis Recording (SAR) tapes. Each Center is required to record a minimum set of SAR categories, but may record additional categories for troubleshooting purposes. Each tape holds between about 15 minutes and an hour of data, depending on the activity level at the time.

The Automated Radar Terminal System (ARTS) computers at most terminal facilities record data on disk packs. Each disk pack holds about 80Mb of data and a typical terminal facility might use between one and two disk packs per day. However, for any particular application only a subset of the data would be required, and experience using the data to analyze aircraft flight tracks suggests that the useful data on one disk pack might compress to about 5Mb. Since the radar track data are used to support airspace and airport planning studies, such as noise and capacity analyses, many facilities have developed procedures for transferring the data. A common approach is for the user to provide a blank disk pack that is inserted into the rotation cycle. After 14 days, when the disk pack would normally be reused, it is returned to the user. Some facilities have developed procedures to download the data from a disk pack to a local computer that can then be accessed by the user over the internet or transferred to more common magnetic media such as a cartridge or tape.

Less detailed information on the position and altitude of each aircraft under positive control is also available from the Enhanced Traffic Management System (ETMS) database supporting the Aircraft Situation Display. These data provide a national perspective, covering all en-route facilities, and are archived on a routine basis by the FAA Air Traffic Airspace Management Program. In addition to providing an opportunity to develop a set of system safety performance measures on a national basis without requiring any new data collection procedures, these data also provide the opportunity for a limited amount of retrospective analysis. While any such measures would be very limited in their scope, and should not be viewed as a substitute for a more comprehensive program to develop safety performance measures at the facility level, their value on an interim basis may be significant. However, further work is required to determine whether any useful safety performance measures can be derived from this data source, given its limitations.

System messages, such as hand-offs or conflict alerts, may provide useful performance measures themselves, or may serve as markers to identify events when other attributes of the system should be recorded. However, as with any other measure, care is required to ensure that the use of events such as conflict alerts in performance measures does not swamp situations of real concern with such a large number of similar events of much less severity that the performance measure becomes worthless as a policy or management instrument, or even fails to measure the safety of the system in any meaningful way.

Airport Surface Data

The situation with airport surface movement data is more difficult. Control towers are much less automated than en-route centers or terminal control facilities, and the controller actions are generally not recorded in the same way. Furthermore. most airport surface radars provide an analog rather than digital signal, which complicates data recording and analysis, and do not automatically record the aircraft track information. Since they need to detect objects other than aircraft, such as ground vehicles, they do not use aircraft transponder returns (termed secondary radar) and indeed do not even detect the transponder returns. This prevents the radar from positively identifying each aircraft. As noted above, this has been partially overcome in the case of the AMASS program by integrating other information.

Another potential source of airport surface movement data is the aircraft tracking information that is acquired by airport noise monitoring systems. Many larger airports have installed these systems. Typically they involve two components, noise monitoring stations that are positioned at various locations in the area around the airport and antennae that detect the transponder returns from aircraft using the airport. The location of each aircraft is determined by multi-lateration from several antennae. The purpose of tracking the aircraft is to be able to determine which aircraft caused a particularly loud event at one of the noise-monitoring stations. Although not intended primarily to track the trajectory of each aircraft using the airport, the data generated by these systems could potentially be used for this purpose. There are a number of practical issues that need to be resolved in order to determine how usable this data source might be for the development of safety performance measures. These include the accuracy of the aircraft position estimates and areas of the aircraft movement area from which transponder returns are typically not received, either because of shielding of the transponder from the interrogating radar signal or because the flight crew deactivate the transponder. Obtaining access to these data on a routine basis would require the cooperation of the airport authority, although this is not anticipated to be a problem.

**Data Analysis Tools**

Use of operational data sources to develop system safety performance measures will require data access and analysis tools. While these will need to be tailored to the data sources and analysis techniques involved, there are a number of existing tools that can provide useful building blocks for the development of appropriate tools for developing system safety performance measures. In some cases the existing tools may be directly modified to generate the performance measures. In other cases they may provide useful experience in data management and analysis, but it may be more efficient to build custom tools specifically designed for the application.

Existing tools fall into three categories:

- FOQA analysis software
- radar and ATC automation data analysis tools
- risk analysis models.

FOQA Analysis Software

Various commercial vendors and government agencies have developed custom analysis software to work with FOQA data. The three principal products currently in use are:

- Ground Recovery & Analysis Facility (GRAF) developed by the Flight Data Company
- Flight Data Recovery & Analysis System (FLIDRAS) developed by Teledyne Controls
- Recovery Analysis Presentation System (RAPS) developed by the Transportation Safety Board of Canada.

In addition, as noted above, the NASA APMS program is attempting to develop more advanced flight-data analysis tools. While the existing FOQA tools are tailored to the requirements of working with flight-recorder data, they may provide a useful basis for developing analysis capabilities for working with ATC system data. However, this would require a mechanism to involve their developers in the activity.

Radar Data Analysis Software

Several analysis tools have been developed by the FAA, its contractors, and airport planning consultants for working directly with radar and ATC automation data, including:

- Data Analysis Reduction Tool (DART)
- Systematic Air Traffic Operations Research Initiative (SATORI)
- Graphical Airspace Design Environment (GRADE), developed by ATAC Corporation
- Flight Track Analysis System (FTAS), developed by Leigh Fisher Associates.

DART is an off-line computer program that can be run at the ARTCCs to analyze SAR tapes in order to investigate a problem or incident. It converts the data on the tapes into a useable format, such as displaying the flight strip data as they would be printed, and prints the information on a high-speed printer for subsequent analysis. While the software may contain useful routines for working with the SAR data that could be adapted for use in other applications, the software itself does not appear well configured in its current form for generating system performance measures on a routine basis.

SATORI was developed by the Civil Aeromedical Institute to support accident and incident investigation by utilizing the radar track data to recreate the radar display as seen by the controller at the time. The radio frequency recordings are digitized and synchronized with the radar display, so that the investigators can “relive” the event. The system provides users with the ability to reconfigure the display to examine aspects of interest, as well as to obtain objective measures of controller actions. The system also has useful applications for training and research, particularly into human factors issues involving controller tasks.

GRADE and FTAS have been developed to support airspace and airport planning and design studies. As its name implies, GRADE is designed to allow users to investigate the consequences for capacity and controller workload of reconfiguring the structure and operation of a particular area of airspace. It utilizes existing radar track data to model the change in performance of a revised configuration, such as a modified route structure or changing the ATC sector boundaries.

GRADE provides a multi-function computer tool for displaying, analyzing, designing, and evaluating air traffic operations in support of airspace redesign, route redesign, flight path and profile analysis, traffic flow and sector loading analysis, obstruction analysis, environmental impact assessment, accident/incident investigation, and operational performance assessment. It has also proven useful for presenting and demonstrating current air traffic operations and proposed alternatives to the aviation community, elected and government officials and the public. The foundation of the GRADE system is a database containing a set of data layers that may be displayed and utilized individually or in combination. The data layers, which can be loaded depending on the needs of a specific application, include: radar tracking data, pilot and controller voice recordings, real-time simulator and fast-time simulation results, airspace structures, navigation aids and fixes, standard instrument departure and arrival routes, airways, controller video maps, terrain, obstructions, airport layouts, political boundaries, waterways, street maps, census data, and noise contours.[2]

FTAS utilizes ARTS track data to provide a graphical display of the routes followed by each aircraft in a terminal area. It can replay a period of time at varying speeds, and assign different colors to various classes of aircraft to facilitate visualization of the track patterns. In addition to its visualization capabilities, it can generate statistical charts and reports and provides the user with the ability to extract altitude and speed profiles, or monitor the distribution of aircraft crossing defined locations. It is primarily used to generate the inputs into airspace and airport simulation models or aircraft noise analysis models, although it also provides a useful capability to explain airspace procedures to airport management or the general public.[3]

## Risk Analysis Models

Risk analysis models provide analytical capabilities to evaluate the risk involved in specific procedures or separation standards. Typically these models adopt a fault-tree approach, in which the probabilities of the expected range of decisions and outcomes are calculated as a function of the procedures involved and the performance parameters of the system. The *Reduced*

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[2] Information provided by Dr. John Bobick, ATAC Corporation.

*Aircraft Separation Risk Assessment Model*, developed as part of the NASA Terminal Area Productivity program in coordination with the FAA Office of System Safety (Cassell, *et al.*, 1997) provides a computational framework for representing the risks associated with changing aircraft separation standards for the final approach to single or parallel runways. While designed for a specific application, the approach can be generalized to address a broad range of situations.

**Conceptual Approach to Developing System Safety Performance Measures**

This section defines a proposed approach to developing a set of system safety performance measures that could be monitored on a routine basis to provide an indicator of trends in the level of safety within the air traffic management system, and to identify developing problems in a timely way. For this to be achieved, it is clearly necessary that the chosen measures do in fact measure the critical aspects of the system performance and are viewed as appropriate measures by those involved in the operation and management of the system. This suggests that the development of an appropriate set of measures needs to follow an evolutionary process, in which the performance measures are refined and expanded as experience is gained in their use. This not only allows resources to be directed at maintaining those measures that turn out to be of the most use, but also assists in obtaining the buy-in of those who must generate the data upon which the measures are based and use the information provided by the measures in their management of the system. The importance of obtaining the understanding and support of those who operate the system on a daily basis cannot be overstated. If the controllers and facility managers come to view these performance measures as a make-work exercise to merely satisfy some reporting requirement, there will be no effort made to ensure that the data on which the measures are based are valid, or worse, personnel may learn how to "game" the system to make their performance look better.

Collecting and analyzing the data upon which a system of safety performance measures is based will inevitably be an expensive undertaking. Therefore, it will be necessary to balance the effort involved against the resulting payoff in terms of improved safety or other operational performance. This too will need to be part of the evolutionary process. As system managers

[3] Information provided by Tom Cornell, Leigh Fisher Associates.

discover which performance measures are useful aids to their decision making, and the results of those decisions become apparent, it will become possible to make a better assessment of the value of each measure.

Controller Workforce Issues

The introduction of any system that appears to be attempting to measure the performance of individuals within an organization is likely to be viewed with suspicion, if not outright hostility, especially if it involves an issue as sensitive as safety. It is important that the management of the program makes it clear that the objective of developing the safety performance measures is to identify and resolve problems before they can reach the point where a controller makes an operational error, or worse. A climate needs to be fostered in which the system safety performance measures are viewed by the controllers and managers as tools to allow them to do their jobs better, rather than introducing a new set of constraints that make an already difficult job even harder. One way to achieve this is to actively involve the controllers in defining the safety performance measures, so that they can be seen to measure those aspects of the system that the controllers feel are relevant measures of safety.

Proposed Approach

In order to initiate a process that can allow appropriate system safety performance measures to be developed and implemented, it is proposed that a number of initial proof-of-concept studies be undertaken to gain experience with identifying useful performance measures and obtaining and analyzing the relevant data. This suggests an approach in which a set of potential safety performance measures is first identified. Then a number of initial proof-of-concept studies can be defined, that would implement some of the potential safety performance measures. Finally, the resources required to implement the proposed studies would need to be assessed. This would provide the FAA with both a range of options in terms of the focus of the studies and the level of resources required, and a vehicle to involve controllers and facility managers in shaping the program.

**Potential System Safety Performance Measures**

The ATC system already generates a number of reports on potentially unsafe situations, resulting from pilot deviations from clearances or operational errors by controllers, including:

- loss of separation between aircraft
- violation of assigned clearance
- aircraft landing or taking off on the wrong runway
- runway incursions.

In addition various warnings are automatically issued by the ATC automation and recorded on the system tapes, including:

- minimum safe altitude warnings
- conflict alerts.

While these could form the basis for a set of system safety performance measures, it should be recognized that not all these events are equally serious. Empirical research is needed to analyze the data that exists in the Operational Error, Pilot Deviation System, and other reports to better define how they can best be used to measure system safety.

The following discussion proposes a number of additional potential system safety performance measures. However, it should be recognized that these are not the product of extensive analysis and have not had the benefit of discussions with those who would be directly involved in their implementation. Although they may well turn out to be useful measures of the performance of the system, their primary purpose at this stage is to illustrate the concept of safety performance measures and provide a basis for further development of an initial set of measures.

<u>Controller Workload</u>

Controller workload forms an important aspect of system safety for two reasons. The first is that heavy workload reduces the ability of a controller to communicate clearances in a timely way, reducing the time that flight crew have to respond to them and their ability to request clarification. Since high workload is often also associated with heavy frequency congestion, leading to a tendency for controllers to speak more quickly, there is a higher likelihood of flight crew misunderstanding or simply missing a message, as well as greater difficulty finding a break in the radio traffic to request information or clarification. The second reason is that under conditions of high workload, controllers are more likely to make an error or overlook a developing situation.

At the other extreme, very low workload can also present problems in maintaining vigilance. However, this would appear to be a less serious problem for system safety than high workload, since not only are positions often combined under such conditions, which tends to maintain workload levels, but the risk of aircraft conflicts occurring under such conditions is generally much lower.

A major difficulty in measuring workload on a routine basis is that the principal indicator of heavy workload, the degree of saturation of the radio frequency, is not readily measurable. While audio tapes of each radio channel are preserved for 14 days, there is currently no convenient way to process this information. Eventually, voice recognition software may advance sufficiently that a digital transcript could be automatically created from each tape, although the technical problems would be daunting. However, for the purposes of workload assessment, it may not be necessary to actually decode the message information. It may be sufficient to know what proportion of the time the controller was transmitting.

In the meantime, indirect measures of controller workload may be adequate. One measure that has been proposed is the time required to accept hand-offs. This can be directly measured from the host computer messages signaling the start of hand-off and its acceptance by the new controller. Under conditions of heavy workload, it can be expected that it will take longer for the controller to accept each hand-off, in part because other tasks may be of higher priority and in part because frequency congestion may delay radio contact being made with the aircraft. Apart from its use as an indirect measure of workload, delayed hand-off acceptance may have safety implications because this in turn delays any clearances that need to be issued to the aircraft to resolve conflicts that may be developing in the new sector.

Other measures of workload can be computed from the number of aircraft in the sector at any one time, and the extent of maneuvering required to resolve conflicts (all of which require clearances to be issued and acknowledged). While the clearances themselves can only be recovered from the audio tapes, they can be inferred from the changes in heading, speed or altitude of the aircraft.

## TCAS Alerts

The frequency of TCAS alerts and resolution advisories provides a direct measure of situations which at least the TCAS logic felt represented a hazard or potential hazard. The difficulty with the use of this as a safety performance measure is that the occurrence of the alert is not automatically recorded by the air traffic control system automation, although the resolution advisory is transmitted by the aircraft's Mode-S transponder and can be acquired from the Mode-S sensor data processing subsystem. Furthermore, the logic behind the alert is well defined, and so it should be possible to infer when alerts would have been issued from the positions and vertical speeds of each aircraft, information on which is recorded.

One side benefit of inferring TCAS alerts rather than directly recording them is that additional information can also be obtained about the flight path of the involved aircraft prior to and following the alert. This will allow the inclusion of incipient situations in which the TCAS alert was not in fact activated, although the situation was such that it could well have been. It may also allow situations to be identified in which corrective action was taken by the flight crew (and presumably air traffic control) prior to the alert.

Since aircraft flight data recorders record TCAS alerts, this presents an opportunity to explore the potential benefits of merging information derived from FOQA programs with that from ATC data sources.

## Runway Conflicts

The runway environment is not only one of the most complex components of the NAS, but one where there is the least potential to recover from error. Aircraft moving at high speed on the runway cannot engage in vertical avoidance maneuvers, and even lateral avoidance maneuvers are very limited. If a runway incursion occurs, the time available to do anything about it is usually only a matter of seconds. Fortunately such incidents are rare, although a high proportion of recent air carrier accidents in the U.S. have been due to this cause. While most runway incursions are reported as pilot deviations, the conditions that lead up to them are not tracked on a routine basis, unless they result in an actual incursion.

For a runway incursion to result in an accident, two conditions must hold: there must be an aircraft crossing or entering the runway, and there must be another aircraft attempting to land or take off on the same runway. Therefore two situations can be considered as potential precursors to a runway incursion accident:

1. a aircraft approaching a runway crossing while another aircraft is on final approach or landing on the same runway or has been cleared to take off;
2. an aircraft being held on the runway waiting for departure clearance, while another aircraft is on final approach to the same runway.

Of course, if appropriate clearances are issued and followed, then no incident occurs. However, the risk is that this does not happen for some reason. Since aircraft crossing active runways and holding departing aircraft on the runway are routine events, it will be necessary to more narrowly define situations of concern. For example, a critical runway crossing could be defined as one where the crossing aircraft is still moving toward the runway and, if it fails to stop, would enter the runway before a departing or landing aircraft has passed the crossing point, but is close enough that it would be unable to stop or execute a missed approach. Similarly, a critical hold could be defined as one where the departing aircraft was held for more than a specified time and the next arriving aircraft was within some defined distance from the runway when the departure commenced its takeoff. The number of times that such situations occur can be viewed as potential safety performance measures. The underlying hypothesis is that the more often these situations occur, the greater the likelihood that one day a pilot will fail to hold until the runway is clear, or the controller will overlook the aircraft holding on the runway and clear the approaching aircraft to land. Since the likelihood of either situation happening may be greater during poor visibility or at night, it may be useful to develop separate measures for these situations (or only compute the measures for these conditions).

**Proof of Concept Studies**

The objectives of the proposed proof of concept studies are threefold:

1. to obtain operational experience with real time data analysis and application;
2. to engage operational entities in the process of developing system safety performance measures;
3. to assess the usefulness of alternative measures.

In order to gain useful operational experience within the constraints of a reasonable expenditure of time and resources, it is important that the studies have a well-defined focus. It is suggested that they be performed using data from a single facility, in order to reduce the volume of data to be analyzed and to simplify the coordination with the facility. Once useful results have been obtained from one facility, the studies can be expanded to other facilities to provide a basis for understanding the differences between facilities. This approach would also allow the development of appropriate analysis tools, without complicating the work by having to address differences in data sources and local circumstances between facilities. Once the tools are found to be working well, they can be more easily modified to cope with inter-facility differences. Finally, this approach will also provide useful experience in addressing controller workforce concerns.

The results of the initial proof of concept studies can be used to assess the usefulness of alternative safety performance measures, which can complement higher-level measures of system safety performance, such as those identified in the FAA Strategic Plan (FAA, 1998). They can also be used to assist in the identification of response strategies to improve system performance. Potential response strategies can be developed in consultation with facility controllers and managers, who can then implement those that they feel are worth trying and are within their authority to do so. Where potential response strategies require higher levels of approval, new equipment, or validation of new procedures, these can be brought to the attention of the appropriate offices within the FAA.

<u>Initial Studies</u>

In the course of the study, it was learned that the NASA Aviation Safety Program has initiated efforts to develop a system-wide air traffic management system monitoring capability as a complement to on-going NASA/FAA development of the Aviation Performance Measuring System (APMS) for monitoring aircraft cockpit operations. FAA and NASA have embarked on joint research efforts aimed at developing the PDARS technology for meeting the needs for a system-wide monitoring and performance measurement capability. The development approach is intended to take maximum advantage of prior work on PDARS by FAA and on APMS by NASA with consideration to compatibility between the systems. The objective of this joint FAA/NASA effort is to develop the PDARS product for nationwide installation to monitor day-to-day operations of the NAS and provide data for measuring system performance

It appears that this program will provide a data management and system performance measurement infrastructure to support more focused studies directed at developing specific system safety performance measures. While a broad range of potential studies could be defined, the following two studies would complement the NASA Aviation Safety Program activities by gaining operational experience with implementing system safety performance measures in different facility environments and addressing different aspects of measuring system safety.

1. This study would focus on techniques to analyze radar track and computer message data for a selected Terminal Radar Approach Control facility. The analysis would examine aircraft separations, speed changes, vectoring and climb and descent profiles. The objective would be to develop algorithms to automatically identify situations requiring atypical controller action to maintain separation, as well as undesired situations, such as unstabilized approaches or traffic conflicts with the potential to lead to TCAS alerts.

   The existing conflict alert logic could be adapted to serve as a basis for algorithms to identify situations requiring controller intervention. The implementation of Mode S downlink of TCAS resolution advisories presents an opportunity to examine a sample of these cases using SATORI or similar software in order to identify characteristics that could be used to define system safety performance measures. Since these advisories are currently transmitted by the aircraft Mode S transponders, they could be acquired and recorded by a separate system linked to the Mode S datalink processor, without waiting for these advisories to be integrated into the ARTS computer message processing. Such a system was fielded in the Boston TRACON during a six-month operational evaluation of the display of TCAS resolution advisories on the controller displays in late 1996 (Carlson *et al*., 1997).

During the six month evaluation, some 2,600 TCAS resolution advisory (RA) events were recorded. Clearly these were not all of equal concern, and in fact none of the controllers interviewed for the evaluation study reported experiencing a safety critical RA event during the evaluation, where an aircraft maneuvered in response to an RA to maintain safety of flight. This suggests that a useful product of the proposed study would be a better understanding of the frequency of occurrence and seriousness of TCAS alerts.

Once such events have been defined and techniques developed to identify them on a routine basis by processing the data from the ARTS disk packs, an analysis would explore whether any correlation appears to exist between the frequency of occurrence of these events and other aspects of the operating environment, such as traffic density or complexity of the traffic flow patterns.

2. This study would analyze data on airport surface movement operations at a major airport. Since ASDE radars do not generally record target positions or even identify targets, the airport could be selected to be one where AMASS has been implemented and an automated noise monitoring system is available to provide supplementary data. One objective of the study would be to compare the accuracy of the two data sources, and to develop algorithms for extracting and storing data on aircraft paths on

the taxiway and runway system. These path data can then be used to determine the rate of occurrence of runway crossings and periods of taxiway congestion, that could lead to ground movement frequency congestion and resulting problems with misunderstood clearances or blocked, missed and garbled messages.

As part of this study, it would be useful to analyze existing data on past runway incursion incidents, such as that contained in the FAA Pilot Deviation System reports, in order to better understand that type of surface movement conditions that lead to runway incursions, and hence the characteristic patterns to be seeking in airport surface movement data sources.

Resources Required

The proposed NASA Aviation Safety Program study examining the application of the PDARS concept and techniques developed under the NASA Aviation Performance Measuring System to air traffic control system performance monitoring has already been programmed. It is envisaged that the other two studies would each last between six months and a year, depending on the detailed scope of work and level of effort, and would require between one and two person-years of effort ($225,000 to $375,000).

It is recommended that further analysis be undertaken to refine the scope of the work involved in each study and prepare a more detailed assessment of the extent of the resources required. This analysis would include discussions with the facilities involved, an assessment of the amount of data processing required, and the development of a detailed work plan.

## Conclusion

The development of a set of safety performance measures that can be computed from routine operational data on an on-going basis offers the potential to provide three useful contributions to improving aviation safety. The first is to provide a means to monitor progress toward achieving the FAA goal of reducing the fatal aviation accident rate by 80% by 2007 from a baseline of 1990-1996. Since fatal accidents are fortunately very rare, waiting to see what happens to the rate before deciding whether safety programs are effective is a very inefficient way to proceed. What is needed are performance measures that are more responsive to procedural and technology changes, and that can be shown to be well correlated with accident risk. The second is to provide a means for facility managers and supervisors to assess the effectiveness of operational changes, to identify sectors or procedures that appear to generate an abnormal number of undesired situations, and to tailor the training needs of individual controllers to aspects where their performance is below that of their colleagues. The third is to provide an early warning indicator of problems that may be emerging from the introduction of new technology, new procedures, or the growth in traffic levels.

Apart from these direct uses of safety performance measures to identify trends and problems in the operation of the national airspace system, they hold the potential to play another important role in the analysis of accident and incident databases, including voluntary safety reporting programs. Currently, the analysis of the data in these reports is limited by a lack of information on the context within which the event occurred, such as how congested the radio frequencies were immediately prior to the event, or how heavy the workload of the controller was at the time. The availability of system safety performance measures that include information of this nature, and that track the changes in the measures over time at each facility on a routine basis, would allow safety analysts to draw on this information for the specific time and location in question when analyzing incident and event reports.

For these goals to be achieved, it will be necessary to develop the appropriate performance measures in close collaboration with those involved in operating the system on a day-to-day basis. The development of suitable performance measures can even act as a vehicle to encourage a thoughtful debate on how to measure safety within the NAS and how to improve it. Those developing system performance measures in other areas of transportation have found that the most valuable part of the exercise is often not the measures that are finally decided, but the discussion that takes place in agreeing what to measure.

The operational aspects of computing appropriate performance measures are likely to be at least as difficult as deciding what to measure. Experience will determine what is useful, and whether the effort involved is justified by the results. Therefore it is proposed that a limited number of proof of concept studies are undertaken as soon as possible to gain experience in developing appropriate analysis tools and techniques, as well as to begin involving the operating community in the process.

One such study has already been proposed by researchers at NASA Ames Research Center to explore the application of concepts and techniques developed under the NASA Aviation Performance Measuring System to air traffic control system data. This has been jointly funded by the NASA Aviation Safety Program and the FAA, and is about to commence. The study would utilize the Performance Data Analysis and Reporting System, that is currently under development, to examine routine operational data in order to identify exceedances from normal operations.

While the development of a comprehensive approach to measuring system safety performance needs to integrate all available information, including that derived from monitoring aircraft flight operations, as well as the operation of the ATC system, there are immediate opportunities to identify and track safety performance measures using ATC system data. Developing and implementing these measures can not only provide near-term indicators of system performance, but in the longer term can provide a consistent data stream that can be integrated into a more comprehensive framework as the other elements of this framework are implemented.

It is recommended that at least two other studies be initiated addressing this aspect of the system, one focusing on terminal airspace operations and the other on airport surface operations. The first study would utilize existing tools, such as those being developed under the NASA Aviation Safety Program, to analyze radar track and system message data for a Terminal Radar Approach Control facility to identify situations that represent a departure from normal operations, including atypical controller intervention to maintain separation, unstabilized approaches, and Traffic Alert and Collision Avoidance (TCAS) alerts. The second study would explore how to effectively utilize the available sources of data on aircraft movement on the airport surface to implement safety performance measures, and would develop algorithms for extracting and analyzing data on the aircraft paths on the taxiway and runway system. The scope and level of effort of these studies could be tailored to the available resources, but it is envisaged that each of these studies would last between six months and a year, and would require between one and two person-years of effort.

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# Appendix

## INDUSTRY CONTACTS

During the course of the study, discussions were held with the following individuals and organizations:

### Federal Aviation Administration

| | |
|---|---|
| James Bedow | AAT-210 |
| Eleana Edens | AAR-100 |
| Carolyn Edwards | ASY-200 |
| Larry Dickson | ATO-241 |
| Thomas Longridge | AFS-230 |
| Jeffrey Loague | AAT-210 |
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| Robert McQuown | AOS-310 |
| James McMahon | ASC-100 |
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### National Aeronautics and Space Administration

| | |
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| Yuri Gawdiak | Ames Research Center |
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### Other

| | |
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| Tom Cornell | Leigh Fisher Associates |
| Joanne Gerg | SABRE Technology Solutions |
| Regina Harris | UTRS |
| Robert Lynch | Battelle/APMS |
| Thomas Mayer | Austin Digital Inc. |
| Tommy McFall | American Airlines |
| Albert Prest | Air Transport Association |
| Nancy Stephens | The CNA Corporation |
| Ted Thrasher | CSSI, Inc. |